The Radiation Environment in Space

Sources of Radiation in Space

- **Galactic Cosmic Rays**
- **The Sun**
  - **The Solar Wind**
  - **Coronal Mass Ejections**

Radiation in Space

NASA research programs for
The International Space Station
Mission to Mars

- **Understand the biological effects**
- **Design adequate shielding**

Galactic Cosmic Rays

Source unknown

Isotropic

Fluence constant over time

Figure removed due to copyright restrictions.
Figure 2.1 in [SSB-Crew Hazards].
Commission on Physical Sciences, Mathematics, and Applications, Space Studies Board (SSB). *Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies.* Washington, DC: National Academies Press, 1996.
See http://books.nap.edu/books/0309056985/html/14.html#page_bottom.

Galactic Cosmic Rays

Broad energy distribution

Peak at about 1 *GeV/nucleon*

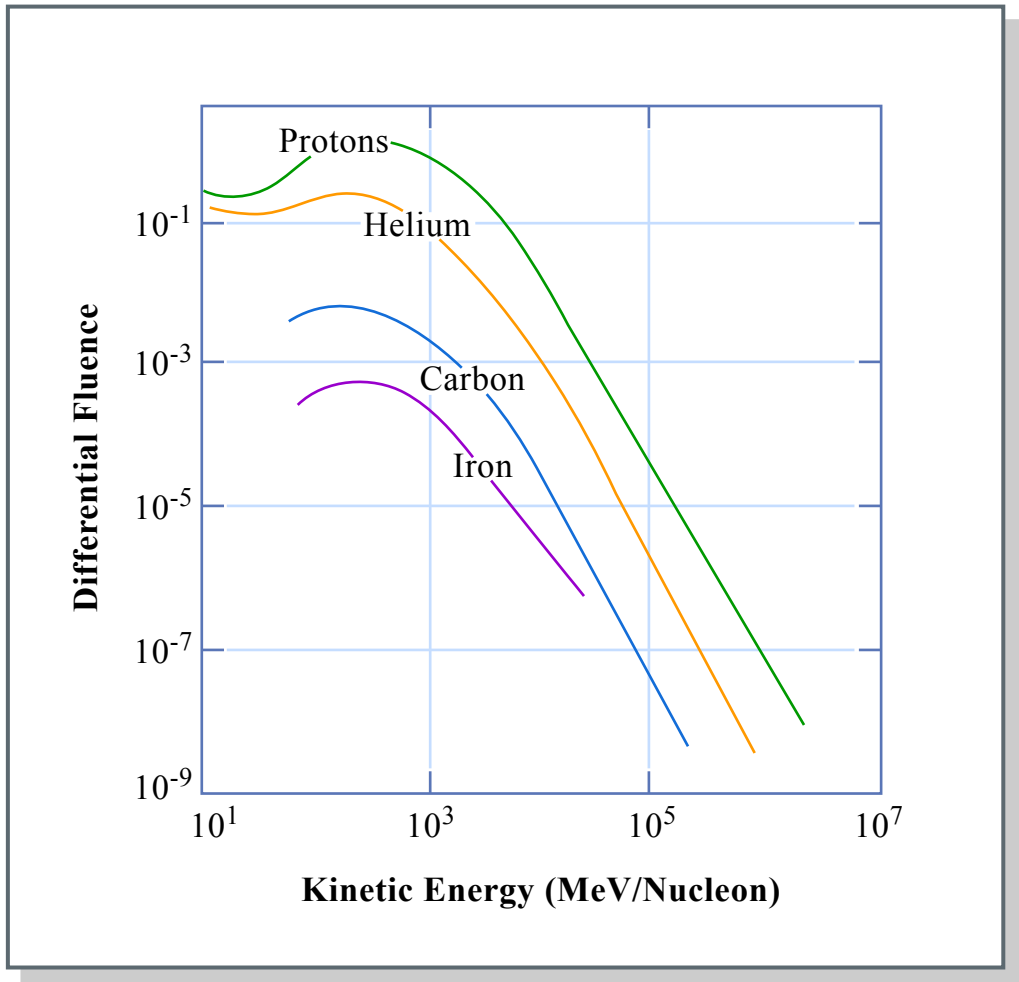

Figure by MIT OCW.

Galactic Cosmic Rays

Attenuation in the upper atmosphere

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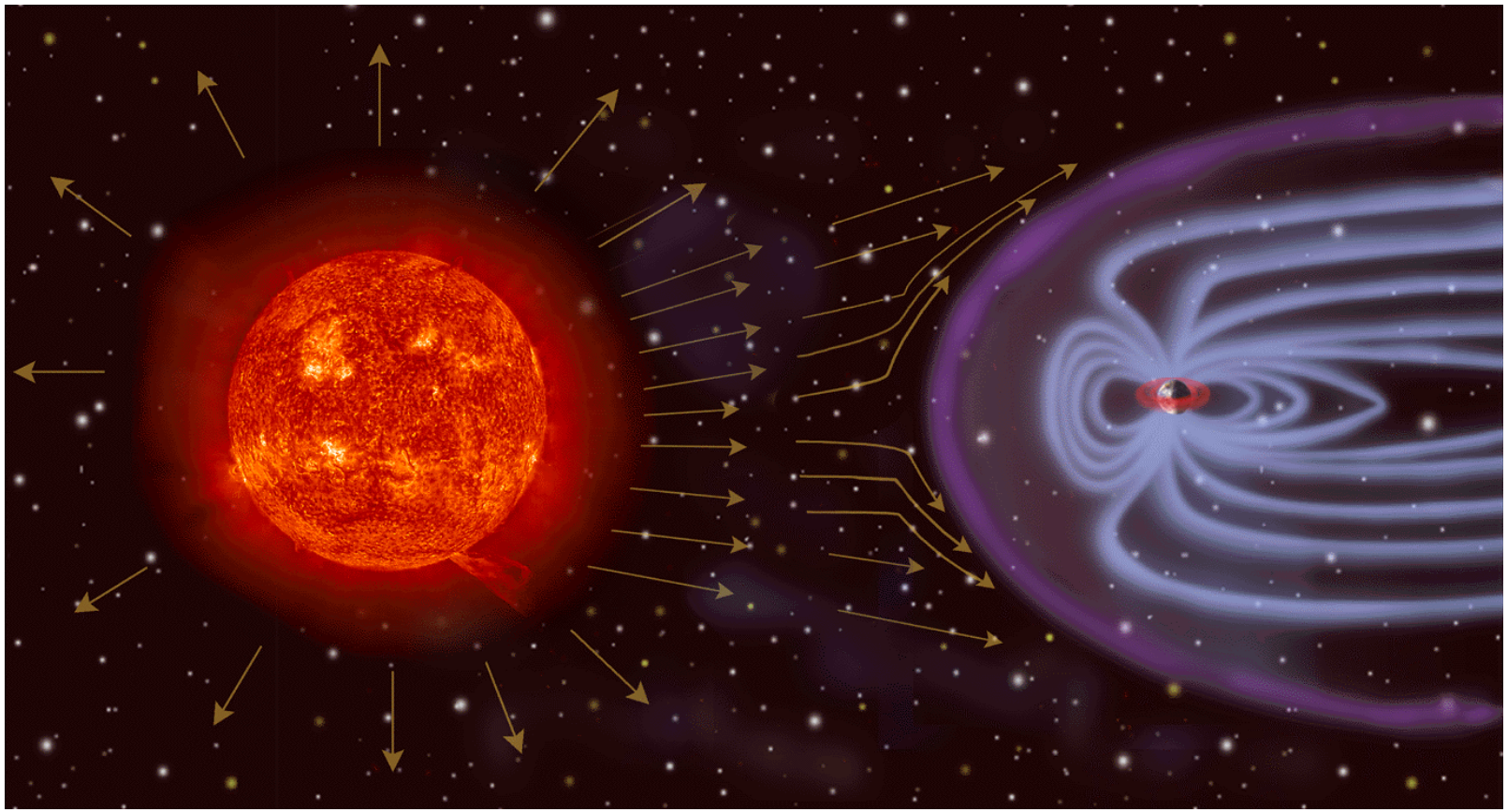
Radiation from the Sun



Courtesy of NASA. “Living in the Atmosphere of the Sun.” [updated 20 Jan 2000, cited 29 March 2004.]
http://www-istp.gsfc.nasa.gov/exhibit/main.html

Radiation from the Sun

The solar wind deforms the Earth's magnetic field lines

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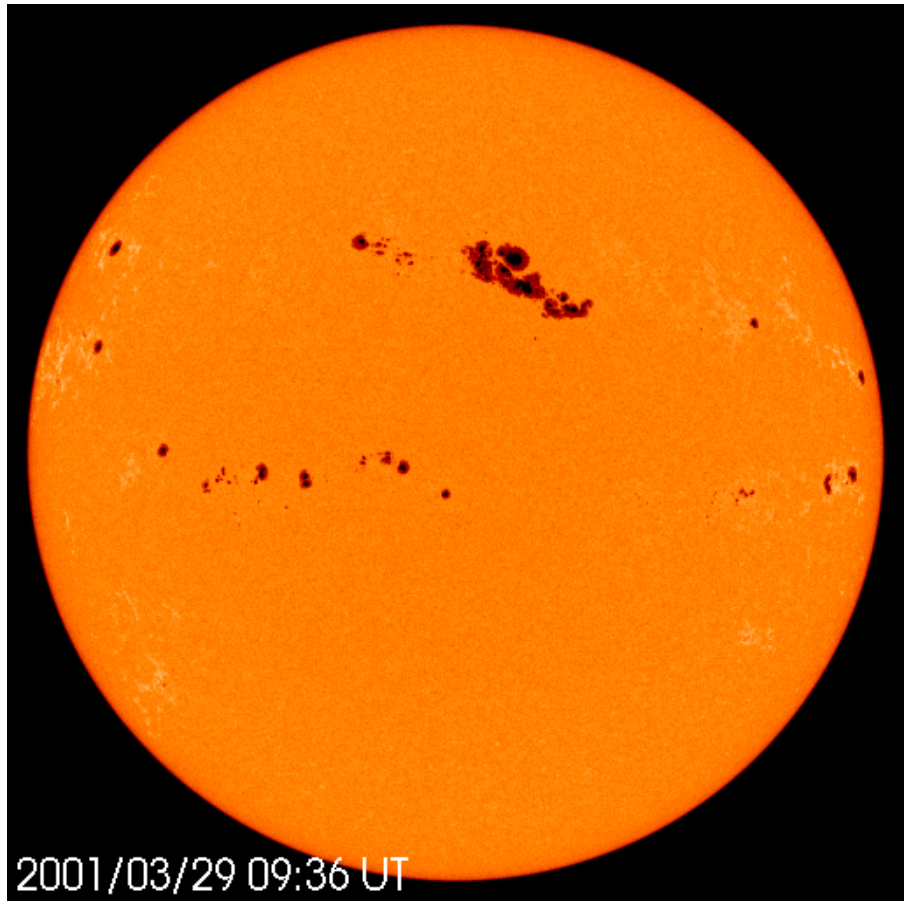
Radiation from the Sun

Sunspots

Observed for centuries

Occur in an 11 year cycle



Courtesy of NASA Goddard Space Flight Center . [updated 30 March 01, cited 29 March 2004.]
http://www.gsfc.nasa.gov/gsfc/spacesci/solarexp/sunspot.htm

Radiation from the Sun

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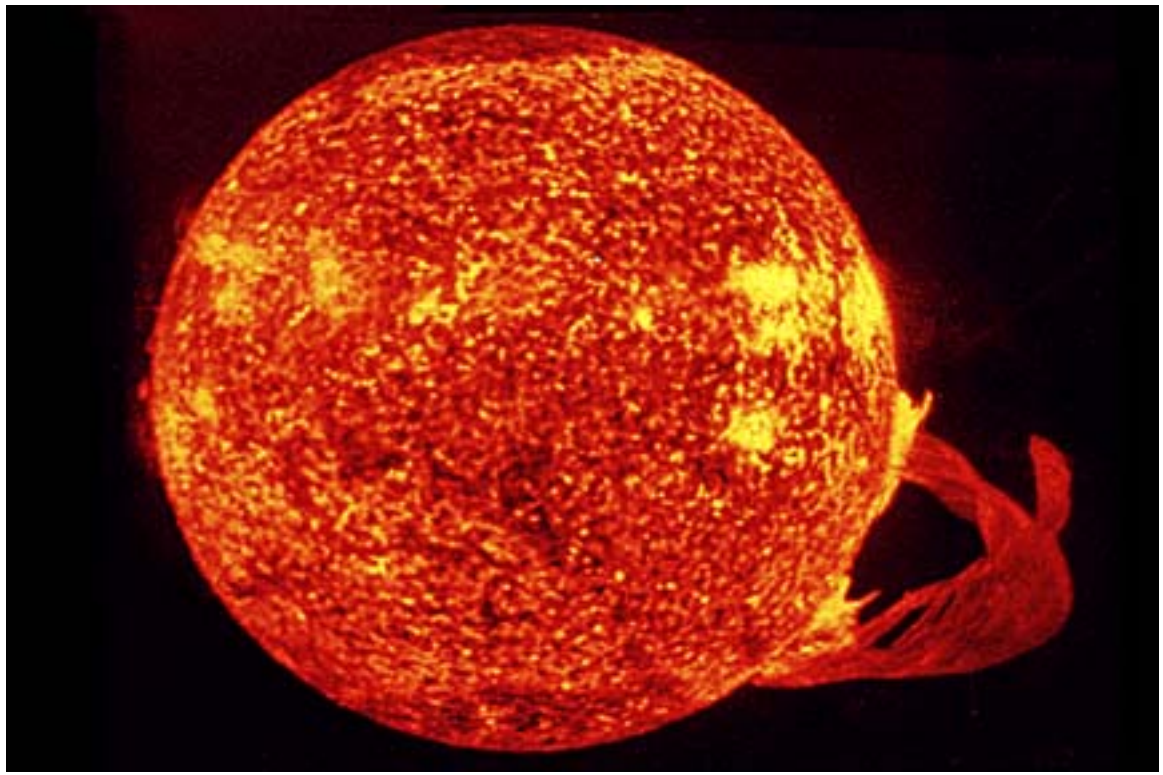
During maximum sunspot activity, there is an increased likelihood of solar flares and coronal mass ejections.

Radiation from the Sun

Solar flares

Associated with production of high energy particles, mostly protons.

Potentially lethal doses



Courtesy of NASA. "Our Magnificent Sun." [cited 29 March 2004]
http://cossc.gsfc.nasa.gov/images/epo/gallery/solar/
1996 photo from Skylab

Violent Space Weather

High Energy Coronal Mass Ejections produce "shocks"

- **Highest energy particles reach Earth in 10 – 100 min**
- **Particle fluence increases by many orders of magnitude**
- **Astronauts directly exposed risk lethal radiation doses**
- **Spacecraft design must include "storm shelters"**
- **A network of satellites and ground stations monitor the sun for signs of SPEs**

Violent Space Weather

Coronal mass ejection, or solar particle event

Image removed due to copyright restrictions.

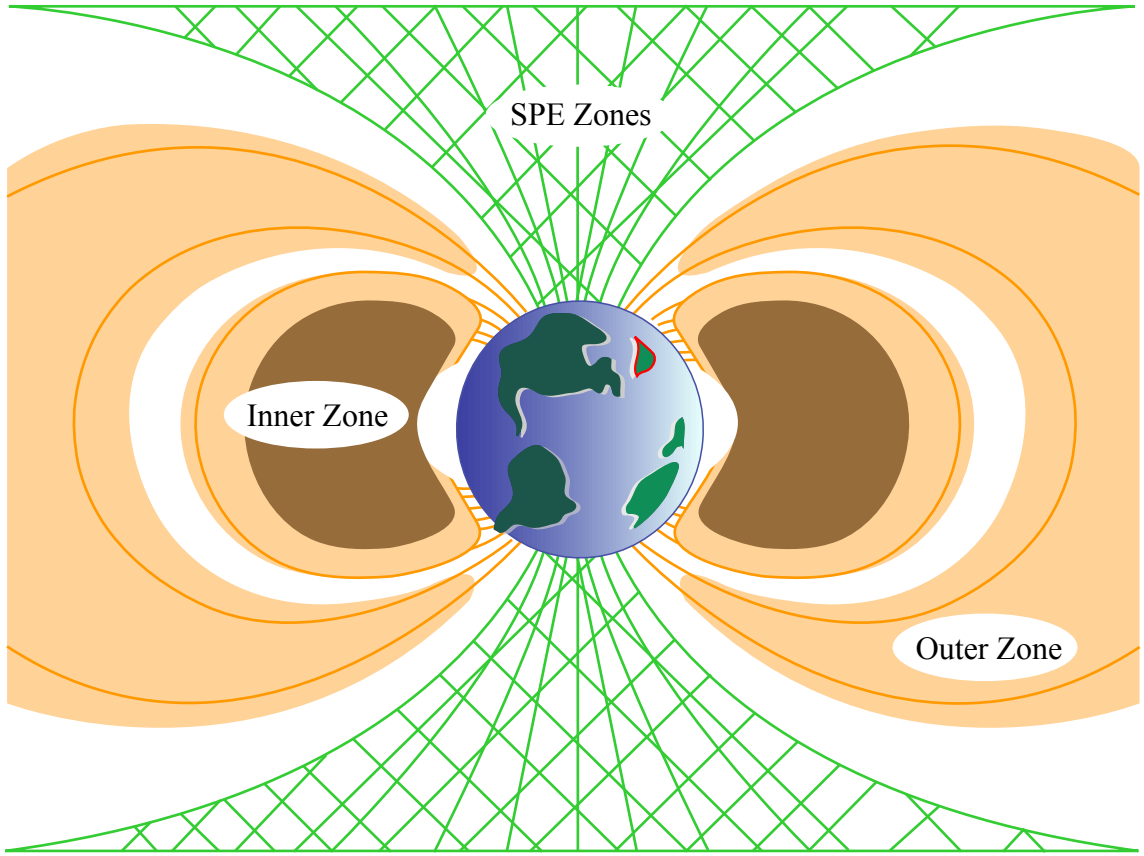
Figure 4.1 in [SSB-Space Station].
Commission on Physical Sciences, Mathematics, and Applications, Space Studies Board (SSB). *Radiation and the International Space Station: Recommendations to Reduce Risk.* Washington, DC: National Academies Press, 2000.
See http://books.nap.edu/books/0309068851/html/40.html#page_middle.

The van Allen Radiation Belts

Inner Belt
mostly protons
E ~ 10 MeV

Outer Belt
mostly electrons
E up to 10 MeV

"Horns" dip in at the poles



The radiation environments of the International Space Station.The figure shows the three regions of space around Earth where penetrating radiation occurs. The inner and outer radiation belts each have an electron and ion component.

Figure by MIT OCW.

The van Allen Radiation Belts

Image removed due to copyright restrictions.

The van Allen Radiation Belts

- Degrade satellite components
- Background noise in detectors
- Errors in digital circuits
- Electrostatic charge-up in insulators

- Present a threat to astronauts

- Apollo missions: largest dose component was from travel through the van Allen radiation belts

The van Allen Radiation Belts

NASA limits the time spent in high-dose regions of the inner radiation belt.

Image removed due to copyright restrictions.

The South Atlantic Anomaly

Image removed due to copyright restrictions.

Figure 1.2 in [SSB-Space Station].
See http://books.nap.edu/books/0309068851/html/9.html#pagetop.

The Aurora

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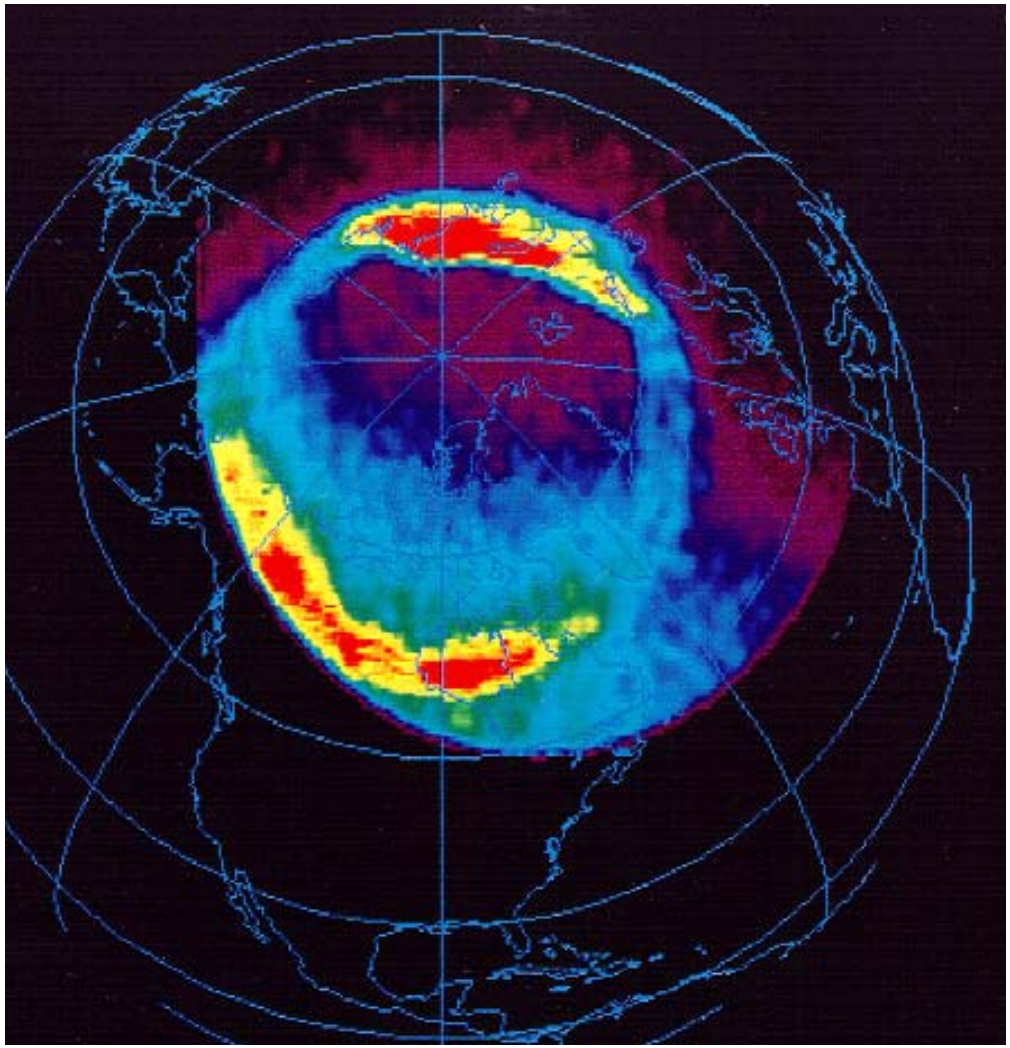
Energetic charged particles entering the upper atmosphere (~ 70 miles up) ionize neutral gas molecules.



Courtesy of NASA. "Space Science Photos: Prior to 1997 [cited 29 March 2004] http://www.gsfc.nasa.gov/indepth/photos_spaceearly.html

The International Space Station

Radiation exposure:

- **Radiation Belts**
- **GCR**
- **SPEs**

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Figure 1.4 in [SSB-Space Station].
See http://books.nap.edu/books/0309068851/html/13.html#page_bottom.

The International Space Station

ISS orbit enters higher dose region at high latitudes

Image removed due to copyright restrictions.

The International Space Station

Image removed due to copyright restrictions.
Figure 1.5 in [SSB-Space Station].
See http://books.nap.edu/books/0309068851/html/14.html#page_top.Im

Radiation in Space

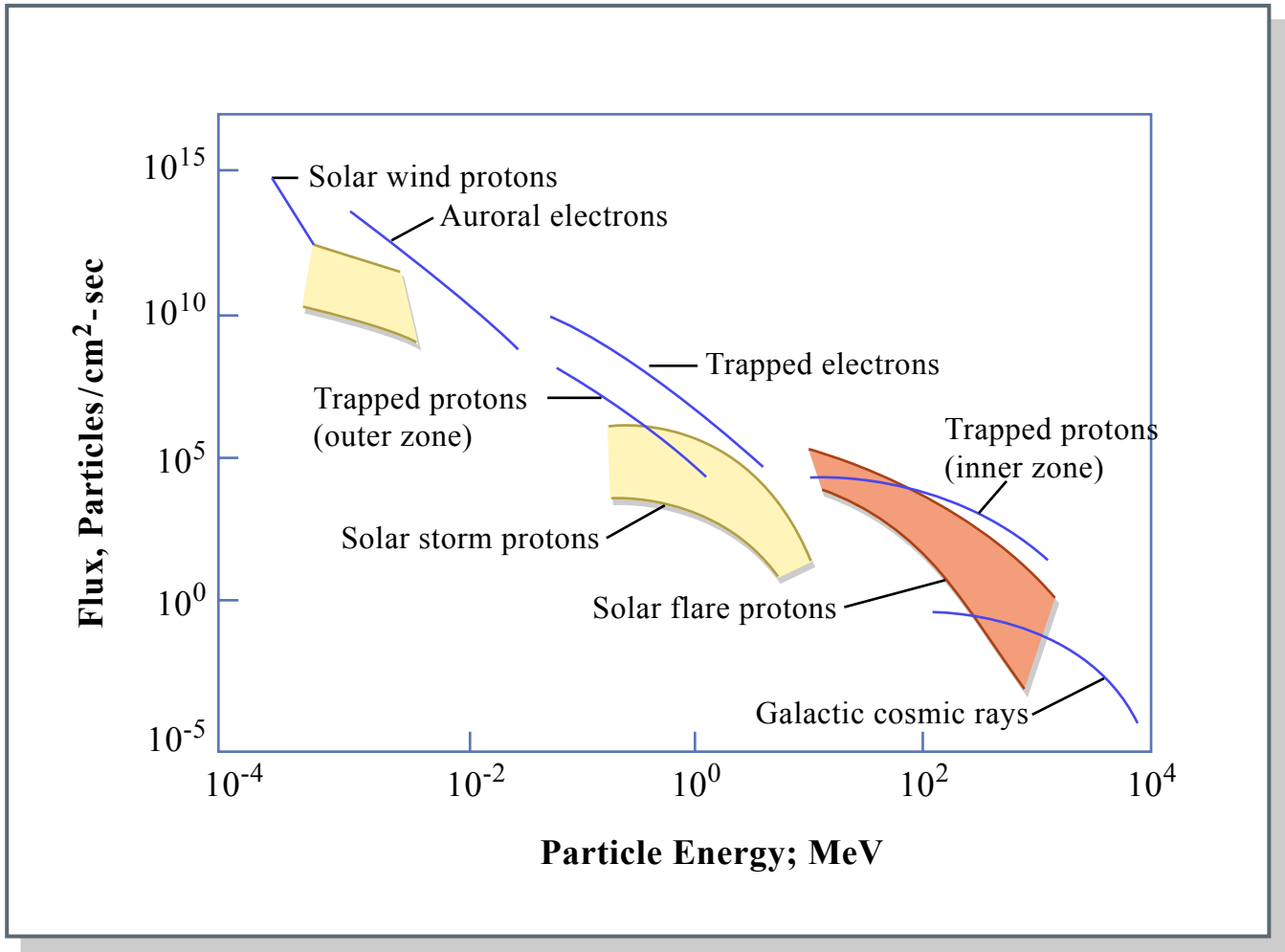

Figure by MIT OCW.

Biological Effects

NASA has invested much research effort into the biological effects of the radiations in space.

Protons:

- **RBE close to 1**
- **Biological effects fairly well known**

GCRs:

- **Fluence is low**
- **Biological effects are poorly understood**
- **May represent the greatest risk**

Galactic Cosmic Rays

Fluence rate, outside the earths magnetic field

- **4 protons/cm^2/sec**
- **0.4 helium ions/cm^2/sec**
- **0.04 HZE particles/cm^2/sec**

For a 100 μm^2 nucleus, *every cell nucleus in the body* would be hit by:

- **a proton once every 3 days**
- **a helium ion once every month**
- **an HZE particle once per year**

NASA's Dilemma

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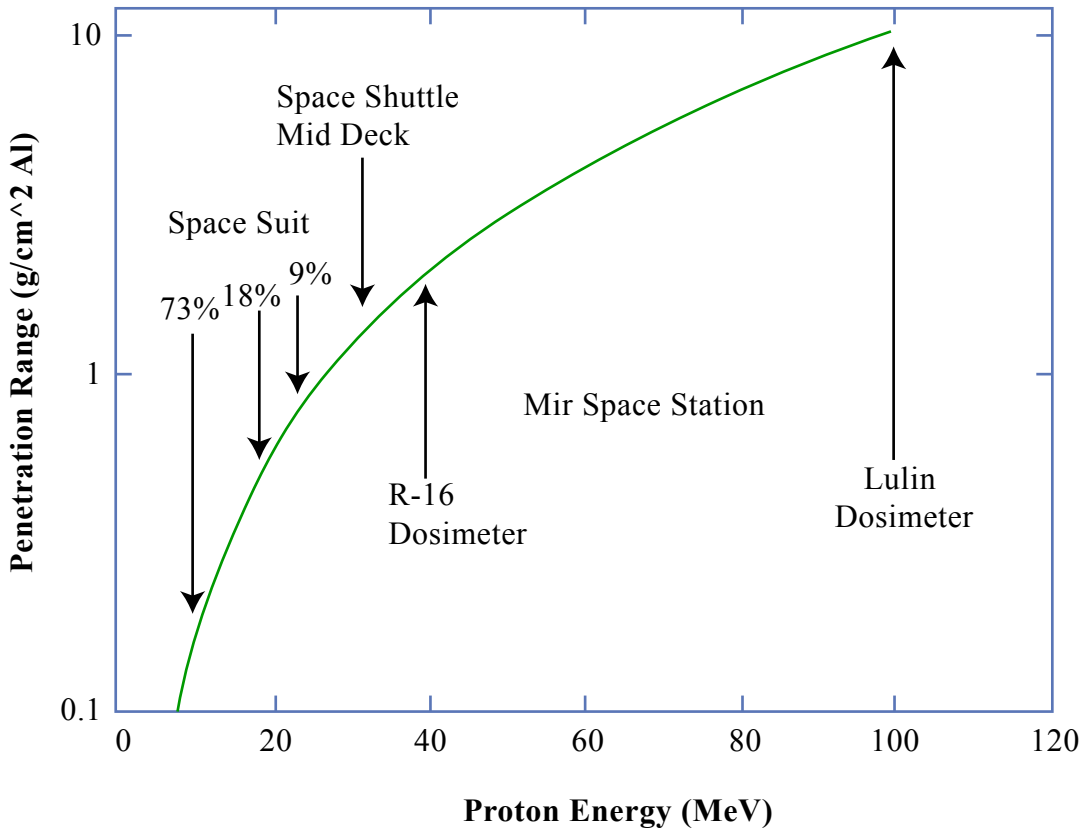
Shielding



Range-energy curve for protons showing energies capable of penetrating various items of space hardware.

Figure by MIT OCW.

The risk to astronauts

Astronauts inside a spacecraft are shielded

The risk is to astronauts outside the spacecraft, or on the surface of the Moon or Mars

Image removed due to copyright restrictions.
Figure 2.3 in [SSB-Crew Hazards].
See http://books.nap.edu/books/0309056985/html/16.html#pagetop.

Early Biological Effects of Radiation

Radiation Sickness

- **Occurs within a few hours**
- **Nausea, vomiting**
- **Doses: > 1 Sv in less than 1 day**

Acute Radiation Syndrome

- **Occurs within 2-4 weeks**
- **Bone marrow suppression doses: 1.5-2.0 Sv**
- **Lethal doses (whole-body) 10% at 3 Sv; 90% at 4 Sv (with no countermeasures**

Skin

- **Erythema (reddening) occurs at about 6 Gy**
- **15-20 Gy will cause moist desquamation**

Hair loss

- **At doses of ~ 6 Gy or higher**

Early effects are unlikely unless an astronaut is exposed while in a non-shielded environment.

Late Biological Effects of Radiation

Cancer

CNS damage

Cataracts: threshold 1.5-2 Gy low-LET
(protons similar to low-LET, data in primates)

Late effects are the major concern following exposure to radiation during spaceflights

Damage to the CNS

HZE effects in the CNS

Premature aging?

Experiments underway in rats

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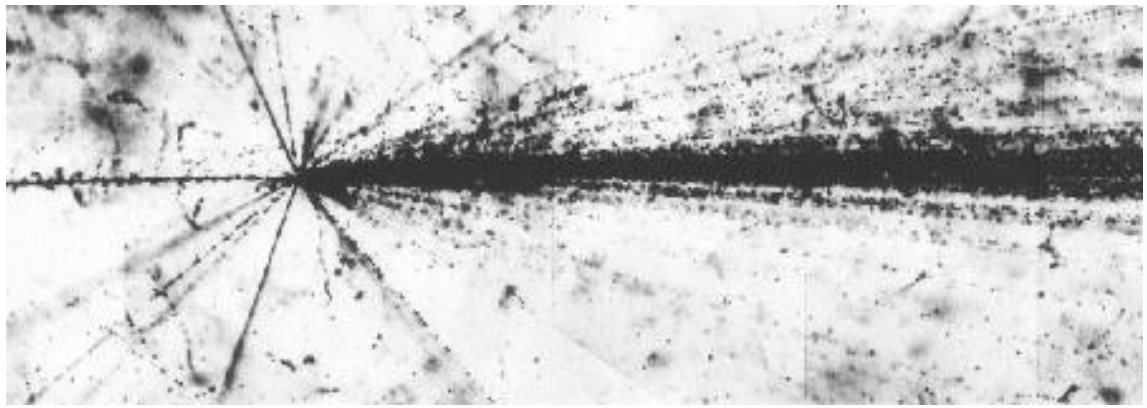
Figure 2.7 in [SSB-Crew Hazards].
See http://books.nap.edu/books/0309056985/html/25.html#page_top.Im

Shielding



Source: NASA. "Cosmic Rays." [updated 25 Nov 2001, cited 29 March 2004]
http://www-istp.gsfc.nasa.gov/Education/wcosray.html

Track structure of a cosmic ray collision in a nuclear emulsion.

Image removed due to copyright restrictions.

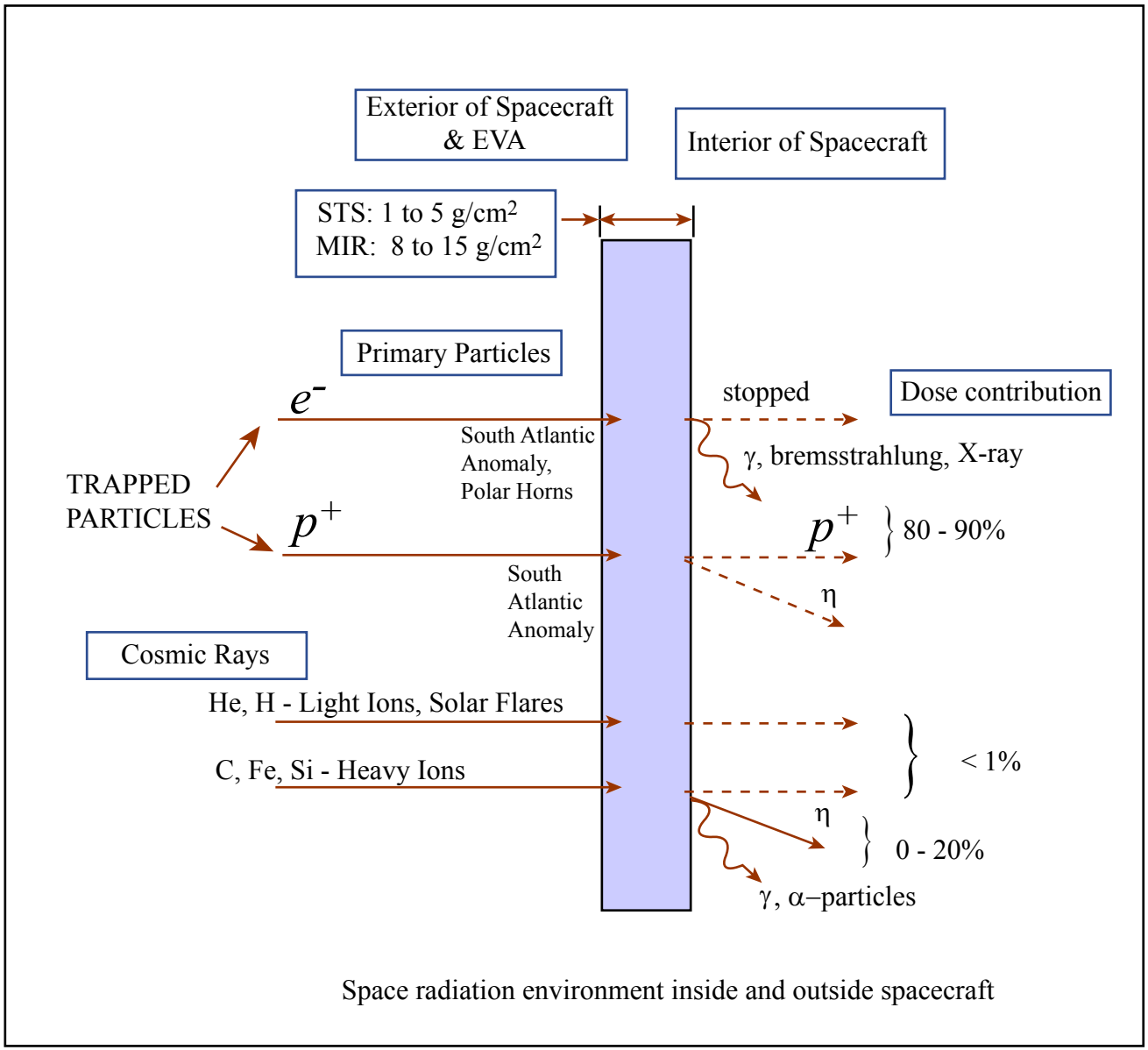
Shielding

GCRs present the greatest shielding problem

Image removed due to copyright restrictions.

Shielding of GCRs

Shielding …can make matters worse!



Space radiation environment inside and outside spacecraft

Figure by MIT OCW.

Shielding of GCRs

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Figure 3.1 in [SSB-Crew Hazards].
See http://books.nap.edu/books/0309056985/html/37.html#page_top.

Mission to Mars

Shielding for SPEs must be part of the design

Image removed due to copyright restrictions.
"Mars TransHab vehicle concept"

Mission to Mars

Characteristics of the inflatable wall and pantry shielding

Inflatable layup and pantry shield materials list	
Inflatable layup	Pantry shield
Nomex	Acrylic box
2 layers combitherm/bleeder cloth	Cashews
Combitherm	Chicken noodle soup
RTV 560 sealant	Chicken rice soup
5 layers kevlar	Grilled chicken
RTV 560 sealant	Peaches
3 layers 4″ polyurethane foam/RTV/Nextel	Fettucine alfredo
Single aluminized kapton	Broccoli au gratin
10 layers double aluminized mylar	Strawberries
Single aluminized kapton	Shortbread cookies
Beta cloth	Trail mix

Mission to Mars

Image removed due to copyright restrictions.

Characteristics of the inflatable wall and pantry shielding.
"Mars TransHab vehicle"

Exposure limits for Astronauts

NCRP (1989) Limits for organ dose equivalents (Sv) for low earth orbit exposures

	Blood Forming Organs	Skin	Lens of the eye
Career	1-4	6	4
Annual	0.5	3	2
30 days	0.25	1.5	1

[Average annual background dose to general population is 0.0036 Sv (360 mrem).]

Mission to Mars

Summary of dose equivalent (cSv) estimates for TransHab inflatable concept

Source	1 y Transit dose equivalent		1.5 y Surface dose equivalent	
	Skin	BFO	Skin	BFO
GCR Solar maximum	33.4	27.9	20.1	17.6
GCR Solar minimum	93.8	72.7	46.5	40.7
August 1972 SEP	63.8	17.0	4.6[a]	2.4[a]

[a] 0-cm and 5-cm depth dose, all others are for CAM.

Exposures to Astronauts

Whole-body dose equivalent (mSv) measured by shuttle passive dosimetry in low-inclination orbits.

Mission	Duration (d)	Low-LET	Neutron	High-LET	Total
STS-4	7.04	0.446	0.156	0.077	0.679
STS-5	5.0	0.278	0.117	0.145	0.540
STS-6	5.0	0.273	0.084	0.138	0.495
STS-7	5.96	0.348	0.014	0.117	0.479
STS-8	6.04	0.348	0.026	0.192	0.566
⟨STS⟩	5.81	0.339	0.079	0.134	0.552

[Annual background is ~3.6 mSv]

Exposures to Astronauts

Apollo:	**5-12 days**	**160-1140 mrad**	**0.01 Sv**
Skylab:	**20-90 d**	**1.6-7.7 rad**	**0.08 Sv**
Shuttle:		**3.2 cGy**	**0.003 Sv/d**
(highest, Hubble repair)			
MIR	**(144 – 468 uGy/day)**		**0.0005 Sv/d**
ISS	**(~0.5 – 2.5 mGy/day**		**0.0025 Sv/d**

Mars mission	**bone marrow**	**60-130 cSv***

***Exceeds the LEO limit for bone marrow of 50 cSv/y**

Average annual background dose	**0.0036 Sv**

Summary

The radiation risks to astronauts are real.

NASA is currently investing in radiation biology experiments using high energy Fe ions.

[High dose rate as opposed to the low dose rate in space.]

The biological effects of GCRs are still largely unknown.